

## **IMPROVED SAFETY FOR DRIVERS AND COURIERS OF COACHES**

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### **ABSTRACT**

According to general accidents statistics a coach is the safest means of transportation with respect to fatalities per billion traveller kilometers. Reasons for this include the existing regulations related to coach safety and the self regulation of the coach building industry. Most passive safety standards are, however, more related to the safety of the passengers and less to the safety of driver and courier. Their typical position at the front of the coach and the fact that most heavy structural parts of the coach are behind their position in the coach, make the driver and courier vulnerable in case of a frontal collision.

The injury risk in specific frontal collisions can be reduced by applying crash technology within the front structure of the coach. By redesign and reorganising the structure and the packaging underneath the driver and courier, the kinetic energy developed in a typical coach-to-trailerback collision can be absorbed whilst maintaining a survival space for driver and courier.

This paper describes the development of a procedure for improvement in the frontal crashworthiness of coaches. Starting with analyses of related accident data and heavy vehicle crash experience from truck testing, numerical simulation, component and full scale testing have been combined to create a new passive safety structural concept. The experience gained has since been used and is demonstrated in the design of a new coach.

### **INTRODUCTION**

According to accident statistics it is generally known that the coach is the safest way of medium/long distance transportation [1]. Comparing the numbers of incidents and casualties, the priorities of making traffic safer would concentrate on other means of transportation. However, all possibilities of

increasing safety should be embraced. In the car industry safety is related to high-tech active and passive measures and the legal requirements are almost endless. In the bus industry the level of safety is mainly self regulative and most of the official regulations are based on active safety. Passive safety regulations are E.C.E. R66 on the strength of the superstructure during a lateral rollover and E.C.E. R80 on the strength of the seats and the anchorages.

Frontal impacts and rollover accidents occur most frequently with coaches. The rollover is 'covered' by R66. No safety requirements exist on frontal impacts. In a combined research programme of BOVA and TNO the bus frontal collision was analysed and the feasibility of controlled energy absorption was investigated.

### **APPROACH**

Available accident databases were studied and the information was compared, focusing on similarities and differences between several countries. Combining this, together with experience from truck crash testing, a typical full scale crash test setup for buses was defined. The present status of an existing coach, in relation to the defined setup, was determined. A concept study was carried out to investigate which parts of the bus were most suited to be involved in crash energy dissipation. Next it was decided in which way the deformation had to take place in order to keep the collision manageable. Several options were assessed on their capabilities and finally a full scale crash test was carried out in which some options were included and tested in a practical environment.

### **ACCIDENT STATISTICS**

In order to develop a procedure to improve the coach structural performance in frontal collisions, it is necessary to have information about the occurrence of these type of accidents. The service of coaches is usually not restricted to the home base. In many cases these vehicles provide transportation to far destinations, often passing one or more countries. Therefore accident data collection should not be restricted to the home country only, but include neighbour countries as well.

Compared with other means of transportation, coaches are involved in only a very small percentage of all traffic accidents [2]. In order to have the

disposal of a statistically interesting database, data collection should take place over a longer period.

In this context the existence of a European accident database would be most appropriate. The parameters which describe a typical accident could then be abstracted. On this basis a procedure for testing could be defined. However, heavy vehicle accident data collection on a European basis is still far away, although many truck and bus manufacturers employ their own accident investigation team. Until these groups start to combine the activities, analyses are focused on brand specific data.

In the Netherlands traffic accidents are registered by the Ministry of Transport. The information in this database is used for global statistic information since no details are recorded. The database is also not complete. The more severe the accident, the bigger the chance it is included. The conclusion from a summary on bus and coach accidents is that frontal accidents are the most dangerous for driver and passengers and that the collision speed is in most cases below 50 kph.

In [3] 4 different German data sources are investigated. It is concluded that the frontal impact and the rollover are the most severe incidents for driver and passenger. From all accidents with buses and coaches frontal collisions are the most frequent accident types. In many cases the damage is on the front at the driver's side. The median velocity at impact is 20 - 35 kph. The average deceleration level is approximately 5g.

## DEFINITION OF TEST SETUP

In the early 90's the truck industry developed a dynamic impact test on a rigid trailer back barrier, simulating a truck rear end collision into another truck [2]. In this way the integrity of the cabine and the cab suspension system can be evaluated in a realistic way. Additionally, dynamic safety devices such as seat belts, pretensioners and airbags can be designed.

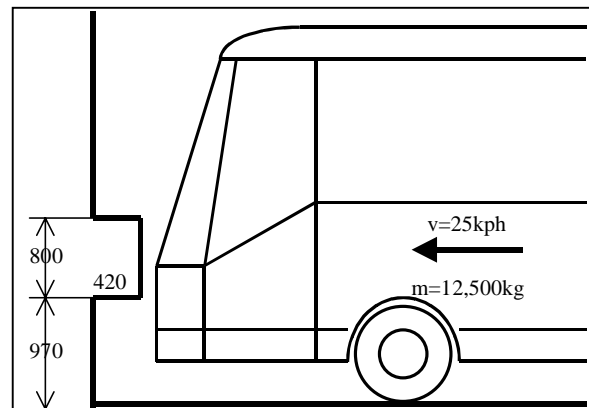
Rear ends of trucks and trailers differ considerably. Ground clearance and geometric layout are not unambiguous. A general and often used height of the barrier is 800 mm and the ground clearance is usually related to the seat reference point. The overhang is variable, but minimal 400 mm. In trucks the chassis beams run all the way to the front. So the cabine

deformation is limited to the size of the overhang. Impact speeds are 30 - 50 kph.

In ECE Regulation No.80 [4] a dynamic test is defined to evaluate seat and anchorage strength. In this sled test an impact speed of 30 - 32 kph is prescribed and the deceleration shall be within an 8 - 12 g corridor. If these values are imposed to a bus collision, this would result in a total deformation of 0.4 - 0.6 m.

Many coaches are not built on chassis frames, but have a supporting space frame structure consisting of rectangular hollow tubes. This implies that, if using an overhanging trailer back structure in a frontal impact test, the bus front might be deformed over more than the overhang distance. And this, in turn, has consequences on the survival space of the driver and the courier. Therefore an impact speed of 30 kph seems too high.

Applying the characteristics mentioned above to a bus frontal collision setup, the following test can be specified (see figure 1).



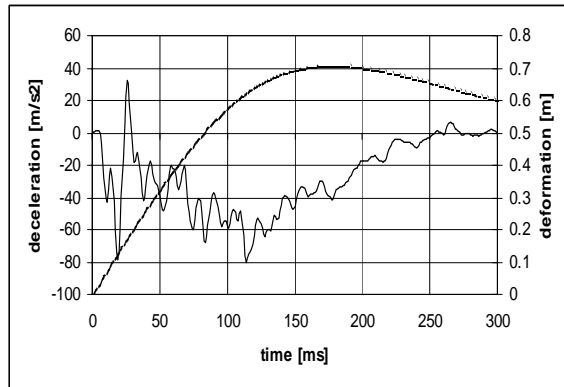
**Figure 1. Test setup of coach/trailerback collision.**

## PRESENT STATUS

The typical position of driver and courier at the front of the coach and the fact that most heavy structural parts are behind their position make them vulnerable in case of a frontal collision. The present status should be known before structural measures can be taken to improve the safety of these occupants. Therefore a full scale crash test was carried out according to the setup of figure 1. For this purpose the front end of a couch was fixed to a specially developed sled of the size of a complete coach. The sled was loaded to complement the total vehicle to

12,500 kg. The kinetic energy is then 300 kJ. The deceleration and displacement at the centre of gravity are shown in figure 2.

The deceleration level is approximately 6 g and was measured at the centre of gravity of the sled. The c.o.g. displacement is obtained by double integration.



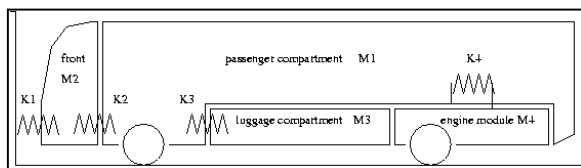
**Figure 2. C.o.g. deceleration and displacement.**

The survival space for driver and courier was reduced and the steering wheel moved in the direction of the driver's chest.

The conclusion from this test is that the deformation in front of the driver should be decreased and that the driver area should remain untouched, mainly by keeping the steering wheel from penetrating this area. In order to investigate the feasibility of these requirements, a concept study was carried out.

## CONCEPT STUDY

The bus structure was reduced to its principal units and interconnected by non-linear springs. The energy absorption and the matching deformations of the structural members were determined and optimised. The model is shown in figure 3.

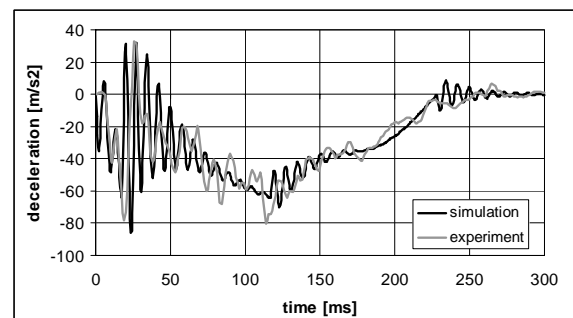


**Figure 3. Spring-mass concept model for feasibility study.**

The model of figure 3 consists of 4 masses and 4 springs. Energy absorption should be arranged in such a way that the passenger compartment is not

damaged during the frontal impact. All the energy should be absorbed by the bus front structure, the luggage compartment and the engine mounting. The model was validated against the test from the previous section, where the bus front was fixed to a 'rigid' sled and all the energy was absorbed by the bus front structure (K1 and K2). In the model all springs except the front springs were made 'rigid'. The springs K1 and K2 were tuned to obtain the result as shown in figure 4.

In the next step the feasibility of absorbing energy not only by the bus front, but also by the luggage compartment and the engine mounting, was explored. Maximum deformation targets were set for each location, based on values which were assumed feasible.



**Figure 4. Validation of spring-damper concept model against full scale experiment.**

These were estimated to 400 mm by the front of the bus, 200 mm at B-pillar location, 500 mm in the luggage floor and 100 - 200 mm in the engine mounting. Now the spring characteristics could be optimised and the desired targets could be achieved to a satisfactory level.

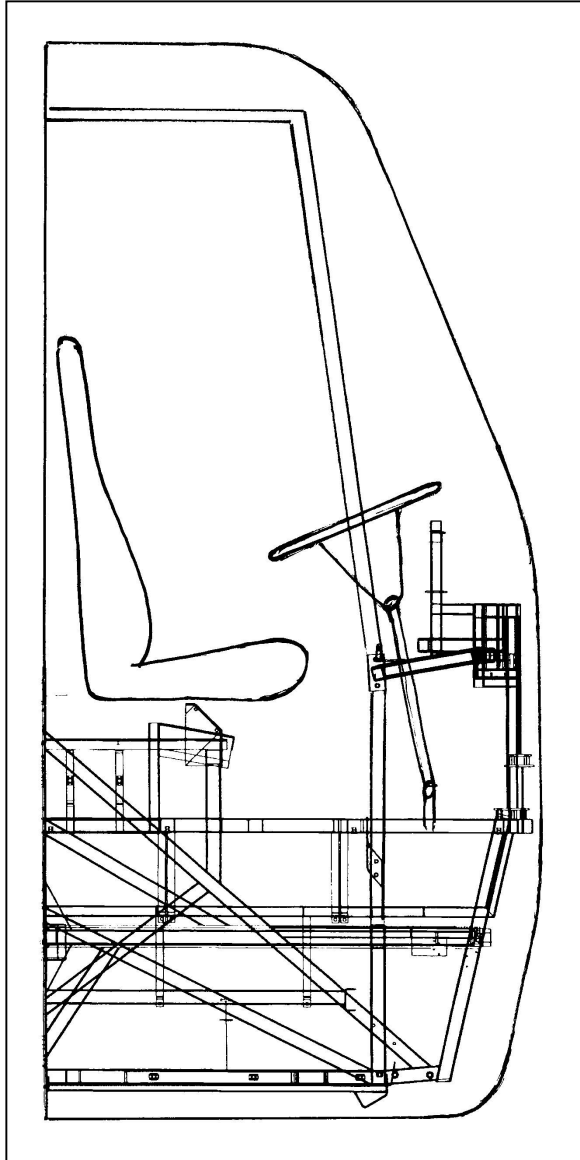
It appeared that approximately 60% of the kinetic energy is absorbed by the front structure (K1) and another 30% by the area around the B-pillar (K2). The energy absorption by the engine mounting is negligible. It was therefore decided to concentrate on optimisation of the bus front structure and to investigate if the energy absorption could be increased to approximately 200 kJ at 400 mm of deformation.

## NUMERICAL SIMULATION

The load carrying structure of the bus consists of steel rectangular tubes. The main structure at the front of the bus is located under the floor and is on

both sides attached to the A-pillars and B-pillars. Above this structure, at the front, the dashboard frame is located. A typical front end structure is shown in figure 5.

A finite element model was developed. The rectangular tubes were modeled with shell elements, allowing cross section deformation when the tube is bent. The frame above the floor is not supposed to contribute to the energy absorption during a frontal crash. However, as its behaviour is very important for



**Figure 5. Typical bus front end structure.**

the survival space of the driver (the global displacement of this frame is responsible for steering column and steering wheel motion during a crash), this structure was modeled with beam elements. The

rear end of the structure, the plane through the B-pillars is assumed to act as a rigid support.

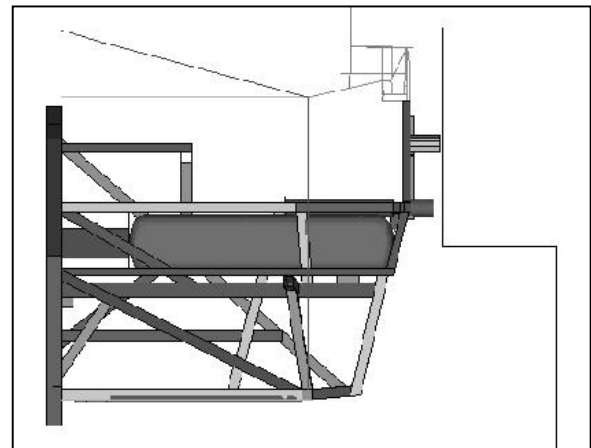
After having validated the model, it was adapted to increase the survival space for driver and courier and to keep the steering wheel away from the driver during the collision. Penetration of the survival space of the driver was prevented by forcing the lower steering column attachment moving more backward than the upper point. In this way the steering wheel pivoted away from the driver.

The floor and the structure directly underneath the floor have a direct contact with the barrier. Therefore, energy should be absorbed mainly in this area.

It was decided not to rely on energy absorption by the frame, because of the uncertainty of the buckling and bending behaviour. Special energy absorbers were used, by including them in the present structure. Additionally, appropriate existing parts were also assigned as energy absorber.

For that purpose a part of the structure in the floor was redesigned to include a crash unit and to rearrange two air vessels in such a way that these parts are addressed in the frontal collision.

The model is completed by adding a rigid body with additional mass which represents the sled where the bus front structure is mounted on. The full finite element model is shown in figure 6.



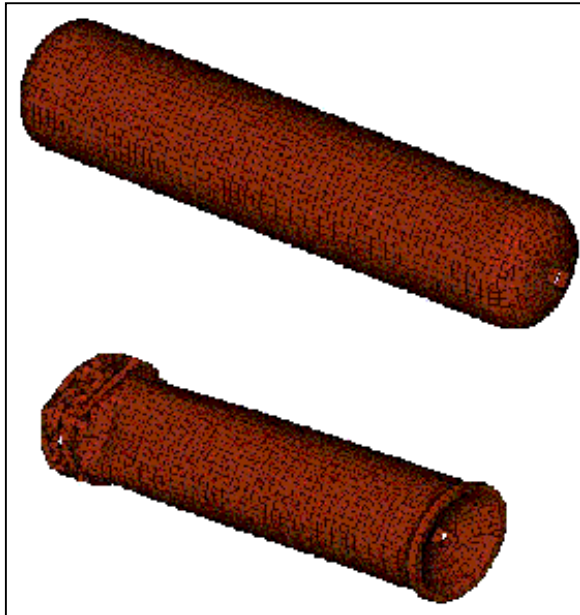
**Figure 6. Full finite element model of bus front.**

### Component tests and validation

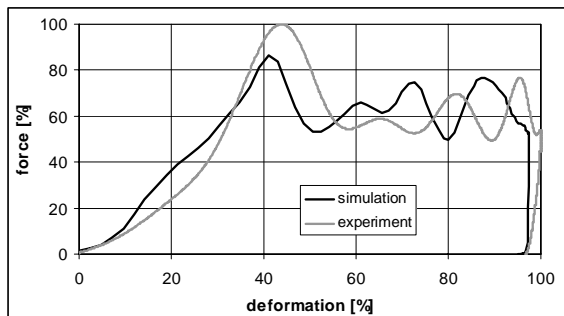
Both the air vessels and the crash unit were first tested and evaluated as components, before being

included in a prototype bus front. The results are shown in figures 7 and 8 and figures 9 and 10.

The energy absorption capacity of the vessel was determined by means of an impact test. The vessel was used to decelerate a 1880 kg sled running at an initial speed of 25 kph. Experiment and simulation were in good agreement. The deformation is shown in figure 7 and the generated force/deformation curve is shown in figure 8. The results were quite encouraging.



**Figure 7. Dynamic impact on air vessel.**



**Figure 8. Validation air vessel.**

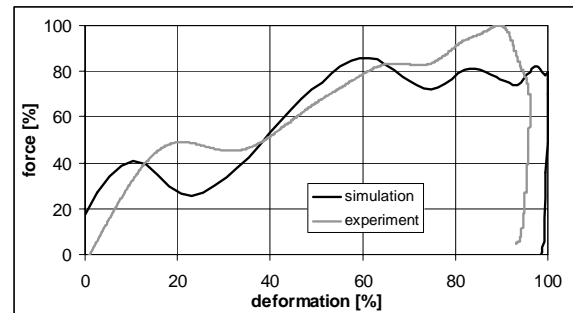
The crash unit was tested in the same way. In order to initiate the right deformation mode of the frame, two crumple tubes were installed at the front. The similarity between test and simulation is shown in figure 9 and the generated force/deflection curves are shown in figure 10.

## Full scale test and validation

The energy absorbing structures described previously worked properly. A full scale prototype bus front is now manufactured. The air vessels are relocated to a more symmetrical position. At the rear end the vessels are supported by the 'rigid' structure. The floor surface is stabilised in vertical and lateral direction on several locations. The total mass of coach front and sled is reduced to approximately 10,700 kg. The test speed is adapted to 22.1 kph so that the total amount of energy to be absorbed is 200 kJ.



**Figure 9. Dynamic impact on crash unit.**



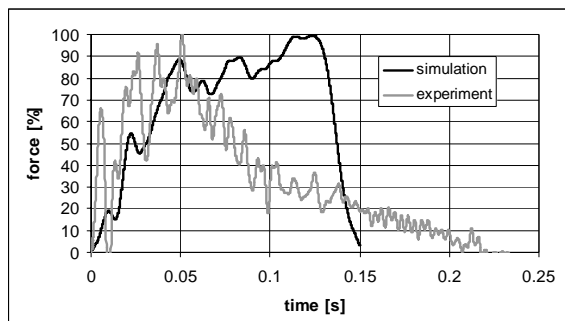
**Figure 10. Validation crash unit.**

The crash test showed the predicted behaviour of the steering wheel column and as a result the steering wheel moved away from the driver. After approx. 45 ms the bus structure starts underriding the barrier frame. This is caused by a downward load, originating from the barrier on the air vessels, which are loaded only partly. Due to the downward load the

front suspension is addressed and the bus front pitches.

The test and the simulation showed a similar behaviour during the first part of the event. The phenomenon of underriding was not seen in the simulation, because the model was supported in vertical direction.

Figure 11 shows the generated force in the simulation and the full scale test. After 60 ms the force drops in the experiment due to underriding. In the simulation, where no suspension was included, the absorption systems still behave well. This results in a maximum cog displacement in the simulation of approx. 420 mm and in the test of approx. 480 mm.



**Figure 11. Force/deformation characteristics from simulation and experiment.**

## CONCLUSIONS

A procedure for improvement in the frontal crashworthiness of coaches is developed and evaluated. It appeared that this procedure was well capable of giving guidance in increasing the passive safety of the driver and courier of a coach in case of a collision with the rear end of a heavy vehicle.

Accident databases were studied and the information was compared. Based on this information, combined with heavy vehicle crash experience, numerical simulation and dedicated research a typical full scale crash test setup was defined, very similar to full scale dynamic trailer back barrier truck testing.

The present status of an existing coach was determined. It appeared that attention should be paid to increasing the survival space for the driver and courier in order to reduce possible injury. Load transfer and crash energy absorption should preferably take place by dedicated structures and structural parts.

A concept study showed that absorption of 200 kJ of energy at the front of the bus would be feasible within a deformation distance of approx. 400 mm. Additional energy could be dissipated directly behind the driver and in the luggage floor. However, it appeared that concentrating on the bus front was the most appropriate.

It was decided to absorb the impact energy by special dedicated structures and existing parts being able to absorb large amounts of energy. A special crash unit was designed and air vessels were relocated for this purpose. Both structures appeared to be able to do the work, provided that adequate support and stability was realised.

A full scale test proved that the bus front was able to fulfil the task. During the first part of the impact the structure behaved as predicted. At the end the structure tended to underride the barrier. At this point the design needs further development to make it more insensible to this type of loading.

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